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1993 December 17



Dr. Herschel S. Pilloff
Physics Division (Code 312)
Office of Naval Research
800 North Quincy Street
Arlington, VA 22217-5660

Dear Hersch,

This letter constitutes the annual report of work carried out under ONR Grant No. N00014-93-1-0116 (R&T No. 4124112-08) at the University of New Mexico during the period 1992 December 1 to 1993 November 30.

During the reporting period five people were directly associated with my research group at UNM. Rüdiger *Schack* continued as a postdoctoral fellow, supported by a German fellowship until 1993 November 1, when he became the Center for Advanced Studies Postdoctoral Fellow at UNM; *Schack* works mainly, but not exclusively, on topics not directly related to this grant. Shang *Song*, USC graduate student, continued work toward a Ph.D. in Physics, working on topics directly related to this grant. Chris *Fuchs* and Howard *Barnum*, UNM graduate students, joined my research group.

In addition to the above personnel, several visitors were brought to UNM under the auspices of the Center for Advanced Studies: (i) Ian Percival of Queen Mary and Westfield College visited for two weeks in 1993 June, lecturing about the quantum trajectories approach now being much used in quantum optics; (ii) Gerard Milburn of the University of Queensland visited for a brief period in June, also lecturing about quantum trajectories; (iii) Gershon Kurizki of the Weizmann Institute visited for two and a half months beginning in mid-August, interacting with my group on various topics in quantum optics; (iv) Samuel Braunstein of Technion visited for two months beginning in mid-August, working directly with me on topics supported by this grant; and (v) James Hartle of the University of California at Santa Barbara is spending the fall 1993 semester in northern New Mexico, splitting his time among Los Alamos National Laboratory, the Santa Fe Institute, and the Center for Advanced Studies.

Research during the reporting period was concentrated in the following areas:

- *Caves* and P. D. Drummond of the University of Queensland finished an extensive revision of their long paper on quantum limits to communication rates and re-submitted it to *Reviews of Modern Physics*, where it has been accepted and is scheduled for publication in the 1994 April issue. This paper should become the standard reference for understanding how to apply physical concepts to assessing the performance of communication channels.

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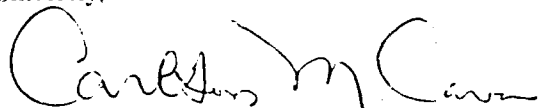
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• *Song* and *Caves* finished their work on quantum limitations on phase measurements made by high-precision interferometry. Their analysis now includes a realistic model of losses in the optical elements, quantum feedback to maintain the interferometer at its operating point, and the use of both squeezed light and light recycling. The research has led to several surprising conclusions about the robustness of squeezed light in Fabry-Perot interferometers and to a unified understanding of recycling configurations. This work constitutes *Song's* USC Ph.D. thesis, which is now nearly finished.

• Braunstein, Milburn, and *Caves* generalized their work on the geometry of quantum states and its relation to high-precision measurements. This work places absolute limits on how well quantum measurements can determine a c-number parameter and establishes new uncertainty principles for a parameter and its conjugate operator. During Braunstein's visit, previous work was generalized from pure states to mixed states, thus establishing a natural geometry on density operators and giving new, tighter uncertainty principles for mixed states. Braunstein has drafted a short initial paper, by him and *Caves*, and is working on a longer paper by all three contributors. *Fuchs* has begun applying these ideas to improve the Holevo bound on quantum communications.

During the reporting period *Caves* was an invited speaker at the Annual Meeting of the Optical Society America, held in Toronto during 1993 October 4-8.

Sincerely,



Carlton M. Caves

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Publications published

1. A. S. Lane, S. L. Braunstein, and C. M. Caves, "Maximum-likelihood statistics of multiple quantum phase measurements," *Physical Review A* **47**, 1667-1696 (1993).

Publications submitted

2. C. M. Caves and P. D. Drummond, "Quantum limits on bosonic communication rates," *Reviews of Modern Physics*, to be published.

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